Issued February 15, 1911.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN 429.
[Superseding 268.]

INDUSTRIAL ALCOHOL:

SOURCES AND MANUFACTURE.

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., October 26, 1910.

Sir: This report constitutes the second revision of a bulletin on industrial alcohol (No. 268) first issued in 1906 and slightly revised in 1907. Its object is to furnish concise and authoritative information regarding the sources and the general processes of manufacture of denatured alcohol, in response to the many inquiries addressed to the department on this subject. It embodies most of the material contained in the earlier editions, together with the results of later work the scientific details of which are given in Bulletin 130 of the Bureau of Chemistry, entitled "The Manufacture of Denatured Alcohol." Farmers' Bulletin 410, on "Potato Culls as a Source of Industrial Alcohol," contains more specific information as to the methods of manufacturing industrial alcohol from this and other wastes. I recommend the publication of the manuscript herewith as a new Farmers' Bulletin superseding No. 268.

Respectfully,

H. W. Wiley,
Chief, Bureau of Chemistry.

Hon. James Wilson,
Secretary of Agriculture.

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INDUSTRIAL ALCOHOL: SOURCES AND MANUFACTURE.

ALCOHOL AND DENATURED ALCOHOL DEFINED.

ALCOHOL.

The term alcohol, as used herein, signifies that particular product which is obtained by the fermentation and distillation of solutions of sugar, and which is known to chemists as "ethyl alcohol." It is a colorless and mobile liquid which has a peculiar "spirituous" odor and a sharp and burning taste. When it is left in a crude condition, both its odor and its flavor are rendered somewhat disagreeable by impurities which originate in the earlier stages of manufacture; but when it has been purified thoroughly—in which state it is commonly known as "neutral" or "cologne" spirit—it acquires a distinctly agreeable smell. It mixes freely with water, in all proportions; and, as is well known, it is the essential intoxicating ingredient of all the fermented and distilled liquors. When "strong," or nearly free of water, it dissolves gums and resins very readily, and burns with an intensely hot, pale-blue flame. Because of these characteristics it is used in large amounts in the preparation of certain varnishes, and as a fuel in cases where its cleanliness, intense heat, and freedom from danger of explosion, offset its expensiveness. Alcohol boils at a much lower temperature than water, and it is this fact that makes it possible to separate it, by distillation, from the aqueous solutions in which it originally is formed. Bulk for bulk, it is considerably lighter than water, and mixtures of alcohol and water show fairly regular increases in weight, per unit of volume, in proportion to the percentages of water which they contain. Because of this relation the alcoholic strength of any such mixture can be determined by means of an appropriately graduated alcoholometer. The strength of alcohol solutions may be stated in percentages by volume or by weight, or in United States proof degrees, one such degree corresponding to one-half of 1 per cent of alcohol by volume.

Chemists employ the formula C_2H_5OH to denote the composition of alcohol. This signifies that one molecule, or unit, of the compound substance alcohol is made up of two atoms, or units, of the element carbon (written C), six atoms of the element hydrogen (written H), and one atom of the element oxygen (written O). The percentage composition of alcohol is—carbon (C) 52.12 per cent, hydrogen (H) 13.13 per cent, and oxygen (O) 34.75 per cent.

DENATURED ALCOHOL.

On account of the intoxicating powers of alcohol, its manufacture is prohibited in many communities, and throughout nearly all of the civilized world its production is hedged about with restrictions in the form of excise laws, which, in addition to producing revenue, raise its price to the consumer and tend to diminish its consumption in the form of beverages. However, this increase in cost, due to tax imposition, interferes seriously with the use of alcohol for fuel and for many other legitimate industrial purposes; and therefore many governments have enacted laws which authorize its manufacture, sale, and use, for industrial ends, tax free, upon the condition that it shall first be made unfit for beverage use by the addition of materials which will give it a thoroughly foreign and nauseating odor and taste without making it dangerously poisonous or interfering with the particular industrial purpose for which it is intended. Alcohol which thus has been made unfit for drinking, is called "denatured alcohol." The materials which are used to make it unpotable, whatever their particular nature, are called "denaturants," and the process by which they are dissolved in or mingled with the original potable alcohol is called "denaturing." Some of these materials and the methods of their employment are discussed on page 9.

THE DENATURED ALCOHOL LAW.

On June 7, 1906, an act of Congress was approved which provided for the withdrawal from bond, tax free, of domestic alcohol when rendered unfit for use as a beverage or as an ingredient of medicines by mixture with suitable denaturing materials. The act reads in part as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That from and after January first, nineteen hundred and seven, domestic alcohol of such degree of proof as may be prescribed by the Commissioner of Internal Revenue, and approved by the Secretary of the Treasury, may be withdrawn from bond without the payment of internal-revenue tax, for use in the arts and industries, and for fuel, light, and power, provided said alcohol shall have been mixed in the presence and under the direction of an authorized Government officer, after withdrawal from the distillery warehouse, with methyl alcohol or other denaturing material or materials, or admixture of the same, suitable to the use for which the alcohol is withdrawn but which destroys its character as a beverage and renders it unfit for liquid medicinal purposes; such denaturing to be done upon the application of any registered distillery in denaturing bonded warehouses specially designated or set apart for denaturing purposes only, and under conditions prescribed by the Commissioner of Internal Revenue with the approval of the Secretary of the Treasury.

The character and quantity of the said denaturing material and the conditions upon which said alcohol may be withdrawn free of tax shall be prescribed by the Commissioner of Internal Revenue, who shall, with the approval of the Secretary of the Treasury, make all necessary regulations for carrying into effect the provisions of this act.

Distillers, manufacturers, dealers, and all other persons furnishing, handling, or using alcohol withdrawn from bond under the provisions of this act shall keep such books and records, execute such bonds and render such returns as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may by regulation require.

Such books and records shall be open at all times to the inspection of any internal-revenue officer or agent.

SEC. 2. That any person who withdraws alcohol free of tax under the provisions of this act and regulations made in pursuance thereof, and who removes or conceals same, or is concerned in removing, depositing, or concealing same for the purpose of preventing the same from being denatured under governmental supervision, and any person who uses alcohol withdrawn from bond under the provisions of section one of this act for manufacturing any beverage or liquid medicinal preparation, or knowingly sells any beverage or liquid medicinal preparation made in whole or in part from such alcohol, or knowingly violates any of the provisions of this act, or who shall recover or attempt to recover by redistillation or by any other process or means, any alcohol rendered unfit for beverage or liquid medicinal purposes under the provisions of this act, or who knowingly uses, sells, conceals, or otherwise disposes of alcohol so recovered or redistilled, shall on conviction of each offense be fined not more than five thousand dollars, or be imprisoned not more than five years, or both, and shall, in addition, forfeit to the United States all personal property used in connection with his business, together with the buildings and lots or parcels of ground constituting the premises on which said unlawful acts are performed or permitted to be performed: *Provided*, That manufacturers employing processes in which alcohol, used free of tax under the provisions of this act, is expressed or evaporated from the articles manufactured, shall be permitted to recover such alcohol and to have such alcohol restored to a condition suitable solely for reuse in manufacturing processes under such regulations as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, shall prescribe. * * *

It will be seen that this law provided only for denaturing such alcohol as had been made in distilleries subject to the full regulations of the Bureau of Internal Revenue[1] and deposited in the warehouses of such distilleries. Contrary to general expectation, it did nothing toward facilitating manufacture on a small scale in such agricultural distilleries as are operated very generally in Europe. However, in the following year an amendatory act was passed (approved March 2, 1907) which was intended in part to remedy this defect in the original law. The text of this amendment is as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That notwithstanding anything contained in the act entitled "An act for the withdrawal from bond tax free of domestic alcohol when rendered unfit for beverage or liquid medicinal uses by mixture with suitable denaturing materials," approved June seventh, nineteen hundred and six, domestic alcohol when suitably denatured may be withdrawn from bond without the payment of internal-revenue tax and used in the manufacture of ether and chloroform and other definite chemical substances where said alcohol is changed into some other chemical substance and does not appear in the finished product as alcohol: *Provided,* That rum of not

[1] Regulations and instructions concerning the tax on distilled spirits. United States Internal Revenue. No. 7, revised.

less than one hundred and fifty degrees proof may be withdrawn, for denaturation only, in accordance with the provisions of said act of June seventh, nineteen hundred and six, and in accordance with the provisions of this act.

SEC. 2. That the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may authorize the establishment of central denaturing bonded warehouses, other than those at distilleries, to which alcohol of the required proof may be transferred from distilleries or distillery bonded warehouses without the payment of internal-revenue tax, and in which such alcohol may be stored and denatured. The establishment, operation, and custody of such warehouses shall be under such regulations and upon the execution of such bonds as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may prescribe.

SEC. 3. That alcohol of the required proof may be drawn off, for denaturation only, from receiving cisterns in the cistern room of any distillery for transfer by pipes direct to any denaturing bonded warehouse on the distillery premises or to closed metal storage tanks situated in the distillery bonded warehouse, or from such storage tanks to any denaturing bonded warehouse on the distillery premises, and denatured alcohol may also be transported from the denaturing bonded warehouse, in such manner and by means of such packages, tanks or tank cars, and on the execution of such bonds, and under such regulations as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may prescribe. And further, alcohol to be denatured may be withdrawn without the payment of internal-revenue tax from the distillery bonded warehouse for shipment to central denaturing plants in such packages, tanks and tank cars, under such regulations, and on the execution of such bonds as may be prescribed by the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury.

SEC. 4. That at distilleries producing alcohol from any substance whatever, for denaturation only, and having a daily spirit-producing capacity of not exceeding one hundred proof gallons, the use of cisterns or tanks of such size and construction as may be deemed expedient may be permitted in lieu of distillery bonded warehouses, and the production, storage, the manner and process of denaturing on the distillery premises the alcohol produced, and transportation of such alcohol, and the operation of such distilleries shall be upon the execution of such bonds and under such regulations as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury, may prescribe, and such distilleries may by such regulations be exempted from such provisions of the existing laws relating to distilleries as may be deemed expedient by said officials.

SEC. 5. That the provisions of this act shall take effect on September first, nineteen hundred and seven.

This amendment in effect created a class of distilleries in which alcohol may be made for denaturation only, in quantities not exceeding 100 proof gallons daily. In accordance with its provisions, revised regulations were issued by the Bureau of Internal Revenue on July 7, 1907,[1] which interpret the law very liberally, relieving such small distilleries of many restrictions placed upon the operation of larger establishments and making it possible to produce denatured alcohol on a small scale, provided that the economic conditions prevailing in any given locality are such as to make this production profitable. Further reference to the substance of these regulations is made on page 30.

[1] Regulations and instructions concerning denatured alcohol, etc. United States Internal Revenue Regulations No. 30, Revised.

DENATURANTS AND DENATURING.

In order to insure the use of suitable materials for denaturing, the law authorizes the Commissioner of Internal Revenue to prescribe the character of the denaturing materials and the manner in which they shall be employed; and in accordance with this provision a list of denaturants for both general and special purposes has been issued, giving directions for their use and tests for determining their quality or fitness for such use.[1] Among the substances mentioned therein are the following: Wood alcohol, benzin, pyridin bases, camphor, castor oil, caustic soda, nicotin, ether, and acetone.

Indiscriminate use of these materials is not allowed. Most of them are to be used only in the manufacture of "specially denatured alcohol," the sale and use of which are permitted only under special restrictions. In making "completely denatured alcohol," the variety which may be bought freely by the public at druggists' and paint shops, only wood alcohol, benzin, and pyridin may be used. On account of the relatively high price of the pyridin bases, and of the fact that the specifications for "approved benzin" admit the use of an inexpensive petroleum distillate, the following formula is altogether employed at present in making completely denatured alcohol in the United States:

> To every 100 parts by volume of ethyl alcohol of the desired proof (not less than 180°) there shall be added 10 parts by volume of approved methyl alcohol and one-half of 1 part of approved benzin.

It is prescribed in the internal-revenue regulations that every industrial distillery of the class herein considered must have a special alcohol room with cisterns for storing the product of the distillery. In case the distiller intends to denature this product on the distillery premises, he is obliged also to furnish this room with the following apparatus: A weighing tank, which is to be used for gauging alcohol and for no other purpose; tanks for the storage of approved denaturants; sealed measures, for use with the denaturants; a mixing tank, and, if desired, tanks for the storage of denatured alcohol. The labor required in denaturing is furnished by the distiller and his employees, but is carried on under the supervision of a United States gauger assigned for the purpose and in his immediate presence.

MATERIALS WHICH MAY SERVE AS SOURCES OF ALCOHOL.

GENERAL CONSIDERATIONS.

The first essential in the character of a material which is to serve as a source of alcohol is that it shall contain either fermentable sugar or some component which can be transformed readily into a fermentable sugar. This is absolutely necessary, as without sugar no

[1] United States Internal Revenue, Regulations No. 30, Rev., pp. 23-26 and 115-117.

alcohol can be produced. A second essential is that the proportion of sugar, or its equivalent, in the proposed raw material, shall be sufficient to pay for handling the latter. This is very important, for there are many saccharine materials, such as tomatoes and unripe watermelons, the juices of which contain so small a percentage of sugar that all the alcohol obtained would be insufficient to pay for the mere cost of handling. A third requisite is that there shall be an abundant, concentrated, and stable supply of the material. Abundance is an essential, because even a small distillery will use a large amount of material daily. Thus, a plant having an approximate daily capacity of 100 gallons, or two barrels of denatured alcohol, will consume the following amounts of raw material: 200 gallons of rich molasses; or 1 ton of shelled corn; or 4 tons of potatoes, containing about 15 per cent of starch; or 7 to 8 tons of sweet apples, containing about 12 per cent of sugar. A concentrated supply of material is necessary, for if it be scattered over a wide area and must be gathered by hand, the cost for labor becomes prohibitive. The supply must be constant, for it does not pay to build a factory that can be run only at intervals. For example, ripe peaches would undoubtedly be worth distilling in localities where they are grown abundantly and where there are surplus crops, if it were not for the fact that there may not be a surplus more than two years out of five, and that the crop would have to be worked up within the short space of two or three weeks to keep it from spoiling. No distillery could earn the interest on its investment running two months out of five years.

In addition to the points enumerated, other considerations present themselves: Whether the material in question will stand transportation and storage; whether it can be worked with appliances which are to be obtained readily in this country; whether it can be handled by the machinery which is adapted to the bulk of the available material in any given region, or must have special machinery installed to fit it for fermentation; whether it possibly may yield a greater profit if used for some other purpose than distilling, and so on.

CHEMICAL COMPOSITION OF FERMENTABLE MATERIALS.

Knowledge of the chemical composition of a proposed raw material is always essential in determining its availability as a source of alcohol. The proportion of sugar or other fermentable substance which may be present has been mentioned already as being of prime importance. In addition thereto, the percentages of water, ash, crude fiber, and nitrogenous compounds or proteids will always be of interest since the proportions of these components will determine the manner in which a material must be worked. The fat percentage has little interest for a distiller, save perhaps as it may affect the feeding value of the distillery refuse; but it will be stated whenever possible, for the sake of completeness, in such analyses as are given.

It may be said in this connection that the five components just mentioned—water, ash, fiber, proteids, and fat—are always determined and reported as such, but, unfortunately, the fermentable substances—sugar, starch, etc.—are often not determined individually, but are combined and reported as "nitrogen-free extract," the percentage of which is obtained by subtracting the sum of the other components from 100. The value thus obtained for "extract" will of course include not only the sugar and starch, but also the unfermentable pentosans and the sum of the errors made in determining the percentages of the first five components. For these reasons the fermentable material actually present may be lower than the figures for nitrogen-free extract or carbohydrates would indicate, as from 5 to 10 per cent of this extract may be unfermentable. Whenever possible representative analyses have been used showing the amounts of starch, sugar, and unfermentable pentosans as individually determined and not as found by subtraction.

Saccharine Materials.

Agave.—Different species of this plant are used in the Southwest in the preparation of several varieties of distilled alcoholic liquors, and at least one distillery has been erected in the hope of utilizing them as a source of industrial alcohol. It is known that the juice of these plants contains large amounts of sugar at times, and there is every reason to believe that, with proper technical direction, they can be used profitably for industrial purposes.[1]

Fruits.—The average amounts of sugar contained in some of the common fruits are shown in the following tabulation:

Kind of fruit.	Average percentage of total sugars, calculated as dextrose.	Kind of fruit.	Average percentage of total sugars, calculated as dextrose.
Apple	12.2	Pear	10.0
Banana	13.8	Pineapple	11.7
Grape	15.0	Prickly pear	4.2
Orange	5.4	Tomato	2.0
Peach	7.6	Watermelon	2.5

It must not be supposed, however, that it is practicable to obtain all of the sugar in these fruits in a form suitable for fermentation. It would be necessary, in preparing any of them for distillation in a column still, to express the juice from the marc, since the latter, if allowed to enter the still, would impede its working, and obviously a certain proportion of the juice and of the sugar will remain in the marc.

[1] A sample of one of these plants, sotol (*Dasylirion texanum*), was analyzed in the Bureau of Chemistry and found to yield 16 per cent of levulose.

Thus it is estimated that it would be impossible, in working with apples, to obtain more than 75 per cent of the total fermentable material, or about 9 per cent of the weight of apples delivered. On this basis, a ton of average apples should yield about 14 gallons of alcohol. Estimating the cost of gathering culls and windfalls, and of delivering them at the mill, to be $4 per ton, a figure based on actual experience, the raw-material expense for a gallon of alcohol will be at least 28 cents.

In the case of grapes, assuming that approximately 80 pounds of juice may be expressed from 100 pounds of Concords, and that this juice contains 18 per cent of total sugars, a ton of fruit should yield between 21 and 22 gallons of alcohol. If the expense of picking and hauling grapes to the distillery is placed at $6 or $7 a ton—a figure obtained from a grape-growing district in California—the cost of raw material for a gallon of alcohol will be 30 cents.

In the case of watermelon, if a 90 per cent extraction of juice containing 2.5 per cent of sugars is obtained, a ton of melons will yield about 3½ gallons of alcohol. If the cost of gathering and hauling the fruit is set at $2 per ton, the raw-material cost will be not less than 50 cents per gallon of alcohol.

In these three specific cases, it has been assumed that the fruit itself was valueless on the spot where grown, and that it could be delivered at the distillery for the mere cost of gathering and hauling. Even on that basis, it would be too costly to use as raw material in making industrial alcohol. The fact that fruit is extensively used in the manufacture of wines and brandies, has no bearing on the present discussion for the reason that the value of potable liquors bears but little relation to the amounts of alcohol which they contain, but is governed almost entirely by the qualities of their flavors and aromas.

Molasses.—Beet molasses, a refuse from the manufacture of beet sugar, is used on a very large scale abroad, and in several distilleries in this country, as a raw material for alcohol production. Usually, it contains about 50 per cent of sugar, and it generally needs only to be diluted and acidified to prepare it for fermentation. Sometimes a lot will not ferment readily, but generally it is worked without any difficulty. A ton should yield from 75 to 80 gallons of alcohol. At $15 per ton, the raw material for a gallon of alcohol will cost 19 or 20 cents.

Cane molasses contains usually about 25 per cent of water, 20 per cent of nonsaccharine solids, and 55 per cent of sugars. The following figures show the composition of two samples of typical distillery molasses of different origins, one being a Louisiana blackstrap and the other a Porto Rican molasses.

Analyses of two typical kinds of molasses.

Determination.	Louisiana.	Porto Rican.
	Per cent.	*Per cent.*
Water	23.5	24.3
Sucrose	26.6	35.8
Reducing sugars	29.1	18.3
Nonsugars	20.8	21.6
Total	100.0	100.0

Almost invariably, cane molasses needs only to be diluted and yeasted to enter into vigorous fermentation. It is common, however, for molasses distillers to add a certain amount of acid to the fermenting solutions to prevent bacteria from invading them and setting up false fermentations. In some cases sulphuric acid is used for this purpose, as in the beet molasses distilleries, but it is equally common, and probably wiser, to use sour distillery slop to produce the desired acidity. A ton of molasses, having the composition of the Louisiana sample given in the table, will have a volume of about 173 gallons and yield approximately 85 gallons of alcohol. At 3 cents per gallon, for which such molasses could be bought only a few years ago, the cost of the material for a gallon of alcohol would be little over 6 cents. The increasing utilization of molasses as a feeding stuff has advanced its price to from 6 to 10 cents, but at some plantations it is probably still cheap enough to retain its old position as a most advantageous raw material for the distiller.

Sorghum.—A large number of analyses made in the Bureau of Chemistry[1] indicates that the juice of saccharine sorghum has the following average composition:

	Per cent.
Water	81.4
Sucrose	12.7
Reducing sugars	1.1
Undetermined solid matters	4.8
Total	100.0

With a light horse-driven mill, about 60 per cent of the weight of the topped and cleaned cane can be obtained in the form of juice. With a heavy mill, such as is used in cane-sugar manufacture, an extraction of at least 75 per cent should be obtained. An extraction corresponding to 65 per cent of the weight of the cleaned stalks may, therefore, be considered a fair average. On this basis a yield of about 14 gallons of 180° alcohol per ton of cleaned stalks would be obtained. If the latter could be delivered at the distillery at a cost of $3 per ton, the material for a gallon of alcohol would represent a value of about 21 cents. A relatively slight improvement in the

[1] U. S. Dept. Agr., Division of Chemistry Bul. 34, pp. 23 et seq.

quality of the juice and in the extraction would lower the cost of material per unit of production very much. Thus, 1,000 pounds of the juice of the Colman sorghum, containing 14.42 per cent of sucrose and 1.10 per cent of reducing sugars, should yield 12¼ gallons of 180° alcohol. The yields of alcohol to be expected from a ton of cleaned Colman stalks, and the cost of material per gallon of spirit, are shown in the following tabulation for different degrees of juice extraction.

Yields of alcohol from sorghum stalks with varying degrees of juice extraction.

Proportion of juice extracted from stalks.	Yield of 180° alcohol per ton of cleaned stalks.	Cost of material per gallon.
Per cent.	*Gallons.*	*Cents.*
65	15.92	18.85
70	17.15	17.50
75	18.35	16.35

Since the gums and slimy bodies contained in sorghum juice do not interfere in the least with its fermentation, and the plant can be grown readily over a very wide range of territory, it is plain that the material deserves favorable consideration in connection with the manufacture of alcohol, and that it is likely to be utilized in the future in this way.

Sugar beets.—The following figures relative to the composition of the sugar beet may be considered as a representative analysis:[1]

	Per cent.
Water	81.51
Ash	.62
Protein	1.72
Fiber	1.35
Fat	.07
Carbohydrates	14.73
Total	100.00

The records of several experimental fields cultivated at the agricultural experiment stations in California, Colorado, Michigan, and Wisconsin show sugar percentages running from 13 to 16. Fourteen per cent will probably be a fair commercial average for the content of fermentable material in sugar beets as grown at present.

In France, where the beet has been used extensively as a source of alcohol, it has been found necessary to extract the juice for fermentation, using one of the extraction methods employed in the sugar factories. The pulp, while it offers no obstacle to fermentation, forms a jelly on heating which interferes seriously with distillation. Data obtained from the results of actual distillery yields show that

[1] Twelfth Ann. Rept. Ind. Agr. Exper. Sta., 1899, p. 71.

for every 100 pounds of sugar contained in the beets entering the French distilleries, 7.1 gallons of absolute alcohol were produced, equivalent to 8 gallons at 180° proof, which is the minimum strength used in this country for denaturing purposes.

With beets at $4.75 to $5 per ton, the price commonly paid by sugar factories in this country, and a sugar content of 14 per cent, the raw material needed to produce a gallon of 180° alcohol would represent a value of 22 cents. Under present conditions this probably would be a prohibitive price, but the time may come when beets will be used as a source of alcohol in the United States as they are in Europe.

Sugar cane.—Spencer gives the following figures as the average of about 40 cane-juice analyses made at the Magnolia Plantation, La.:

	Per cent.
Water	83.6
Sucrose	14.1
Reducing sugars	.6
Undetermined solids	1.7
Total	100.0

On the presumption that 72 per cent of the total weight of the sugar cane can be obtained by two pressings, as juice of this composition, a ton of cane should yield 16.7 gallons of alcohol. If cane is worth from $3 to $3.25 at the factory, this would make the cost of the raw material for the alcohol about 19 cents per gallon.

Sugar-corn cannery wastes.—The stalks of the sugar corn contain quite large amounts of sugar, analyses made in the Bureau of Chemistry having disclosed its presence in proportions varying between 7 and 15 per cent. Investigations conducted at a corn cannery in Illinois, in 1906, showed that the waste stalks amounted to about 40 per cent of the total weight of corn brought to the factory, and that it was possible to produce from them from 6 to 10 per cent of alcohol, with a safe average of 8 per cent. On this basis about 11 gallons of alcohol should be recovered for every ton of corn delivered to the cannery. Unfortunately, the season during which these stalks are suitable for utilization in the manufacture of alcohol is very limited, and probably it would not pay to put up a distillery to handle them, unless other cheap materials were available for use during the rest of the year.

Starchy Materials.

Certain materials contain an essential part of their fermentable material in the form of starch, even though some of them, like artichokes and sweet potatoes, also contain notable amounts of sugar. They differ from the saccharine materials, in requiring to be "mashed" before they can be fermented. This operation is discussed in detail on page 25.

GRAINS.

Barley.—The average composition of ordinary six-row barley is approximately as follows:

	Per cent.
Water	8.7
Ash	3.0
Protein	11.9
Fiber	5.8
Fat	2.0
Starch	58.9
Pentosans	9.6
Total	99.9

On account of its expensiveness, barley is never used by itself as a source of industrial alcohol. It is, however, used in large quantities in making malt, which operation is described on page 24. The composition of a typical malt is as follows:

	Per cent.
Water	5.9
Ash	2.7
Protein	11.5
Fiber	6.0
Fat	2.1
Starch	48.4
Sugars	12.2
Pentosans	10.6
Total	99.4

It is customary to use about 8 pounds of malt to saccharify 100 pounds of raw grain. Two pounds will be sufficient for mashing 100 pounds of potatoes.

Maize (Indian corn).—The following figures represent the average of a large number of analyses taken mostly from the work of the Illinois experiment station.

	Per cent.
Water	10.0
Ash	1.5
Protein	10.4
Fiber	1.9
Fat	5.2
Pentosans	5.0
Sugars	2.0
Starch	64.0
Total	100.0

A lot of distiller's corn (yellow dent) used in the experimental distillery of this department, and analyzed in the Bureau of Chemistry, was found to contain 72.8 per cent of nitrogen-free extract, including 57.9 per cent of starch and 2.3 per cent of sugars, in addition to pentosans, gums, etc.

The method of working this and other grains is described on pages 23 to 27. One ton of grain, made up of 1,850 pounds of maize and 150 pounds of malt of the compositions given above, should yield 100 gallons of 180° alcohol. At 50 cents a bushel for corn and 65 cents a bushel for the barley necessary to make the malt, the ton of grain will cost about $19, and the cost of raw grain, per gallon of alcohol, will be 19 cents.

Maize is, and always has been, the chief source of industrial alcohol in this country. The ease with which it is raised, its ability to stand transportation and storage, and its low price in past years, have combined to give it a preeminence as a distillers' raw material, which it undoubtedly will retain for many years.

Oats.—This grain, which contains about 50 per cent of fermentable material and which might with care be made to yield about 70 gallons of alcohol per ton, is unsuited to distillery use on account of its greater value as a feeding stuff, and the glutinous nature of the mixture which is formed when it is treated with hot water.

Rye.—A lot of this grain used in the experimental distillery had the following composition:

	Per cent.
Water	9.4
Ash	2.1
Protein	10.7
Fiber	1.9
Fat	1.9
Starch	53.7
Sugars	5.6
Pentosans, gums, etc	14.7
Total	100.0

This material is used very largely in distilleries which produce compressed yeast or rye whisky, and it sometimes is employed in small amounts in the yeast mashes of alcohol distilleries, but it is not suitable for use as the chief ingredient of the mash in an alcohol distillery on account of its expensiveness and though containing about 60 per cent of fermentable matters it rarely yields over 85 gallons of alcohol to the ton.

Sorghum seed.—This grain, regarding which many inquiries are made, has the following average composition, closely resembling that of maize:

Comparison of sorghum seed and Kafir corn.

Determination.	Sorghum seed.	Kafir corn.	Determination.	Sorghum seed.	Kafir corn.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Water	8.3	12.5	Pentosans	4.3	....
Ash	1.8	1.3	Sugars	1.5	....
Protein	13.3	10.9	Nitrogen-free extract	66.3	70.5
Fiber	1.5	1.9			
Fat	3.0	2.9	Total	100.0	100.0

Undoubtedly sorghum seed could be worked in the distillery as corn is and probably would require less cooking and give fully as good a yield, though its use for this purpose has never been tested as far as the writer knows.

Wheat.—What has been said regarding the yield of alcohol to be obtained from rye applies in a general way to wheat also. Although wheat contains nearly 65 per cent of starch and sugars, it is too expensive to be used for alcohol production unless frozen or for other reason unavailable for food purposes.

	Per cent.
Water	10.5
Ash	1.9
Protein	11.5
Fat	2.0
Fiber	2.3
Sugars	2.8
Pentosans	7.0
Starch, etc	62.0

ROOTS.

Artichoke.—The tuber of the Jerusalem artichoke has the following average composition:[1]

	Per cent.
Water	79.0
Ash	1.0
Protein	1.3
Fiber	.8
Fat	.2
Pentosans	1.2
Nitrogen-free extract	16.5
Total	100.0

It is seen that artichokes contain from 16 to 18 per cent of fermentable matter in the form of levulose and inulin, and as the latter may be converted into the former without the use of malt, by merely boiling under pressure, it can be worked very cheaply. When 17 per cent of fermentable substance is present, a ton should yield about 25 gallons of alcohol; and as it can be raised and delivered for about $5 per ton the raw material for a gallon would cost about 20 cents. The tuber has remarkably good keeping qualities and deserves far more attention than it has yet received as a distillers' material.

[1] Behrend, J. Landw., 1904, 52: 127.

Cassava.—The root of the sweet cassava has the following average composition:

	Per cent.
Water	65.0
Ash	.7
Protein	.9
Fiber	1.7
Fat	.3
Starch	25.4
Nitrogen-free extract	6.0
Total	100.0

It is fair to assume that about 80 per cent of the dry matter of the root, or about 28 per cent of the weight of the root itself, is fermentable. On this assumption a ton of roots should produce about 42 gallons of alcohol. At $5 per ton, which would be a fair price with modern methods of cultivation, the raw material would cost about 12 or 13 cents per gallon of alcohol. In so far as is known, cassava has never been used as a source of alcohol. That technical difficulties might arise in handling it is very possible, but the analytical data and cost afford every reason for testing the value as a source of alcohol.

Potatoes.—Following is the average composition of Maine potatoes, as determined a few years ago in the Bureau of Chemistry:

	Per cent.
Water	77.0
Ash	.9
Protein	2.2
Fiber	.7
Fat	.1
Starch	18.3
Sugars, etc., by difference	.8
Total	100.0

Samples analyzed more recently in connection with the work of the experimental distillery were found to contain about 15 per cent of starch and 0.4 per cent of sugars. Liquid wastes from starch factories in Maine were also examined, but did not contain sufficient fermentable material to be of value for alcohol production.

The method of working potatoes is indicated on page 25 and is discussed at length in Farmers' Bulletin 410. For every per cent of starch contained in potatoes they should yield about 1.6 gallons of alcohol per ton. If the tubers contain 16 per cent of starch, a ton should yield over 25 gallons of alcohol; and if they can be delivered at the distillery for $5 per ton, a fair price for culls in potato-growing regions, the raw material for a gallon of alcohol will cost about 20 cents.

In Germany the potato is almost the only material used as a source of industrial alcohol, not only because it offers a cheap raw material, but because it is highly advantageous from an agricultural point of view. It undoubtedly will be similarly utilized in this country in the future.

Sweet potatoes.—The following average data are based on work done at the South Carolina station[1] and may be considered as representing sweet potatoes of good quality:

	Per cent.
Water	66.0
Ash	1.0
Protein	1.5
Fiber	1.3
Fat	.5
Sugars	5.5
Starch	21.8
Undetermined material	2.4
Total	100.0

These roots are seen to contain about 27 per cent of fermentable substances, of which approximately one-fifth is sugars. In storage there is a decrease in the starch percentage and a corresponding increase in that of sugar.

Preliminary experiments conducted at the Bureau of Chemistry indicate that the sweet potato can be mashed in about the same way as the common potato. Undoubtedly there will be some slight destruction of sugar on heating under pressure, but it ought not be such as to cause a serious loss. It does not appear that the somewhat fibrous character of the root interferes with steaming it in an apparatus built for potatoes.

A ton of sweet potatoes, containing about 27 per cent of fermentable substances and costing $8, should yield approximately 38 gallons of alcohol at a cost of about 21 cents a gallon for raw material.

MANUFACTURE OF ALCOHOL.

HISTORICAL NOTE.

Although there are processes by which alcohol may be made synthetically in the laboratory, they are too complicated and expensive to have any practical manufacturing value. Therefore the method which has been used for many centuries, namely, the distillation of fermented-sugar solutions, is still employed in alcohol production. This manufacturing process is very ancient, having been used probably as early as 800 B. C. It seems for many centuries to have been employed only in preparing spirituous beverages of somewhat

[1] South Carolina Bul. 136, 1908, p. 11.

higher alcoholic strength than could be obtained by fermentation alone. The first stills were very crude and simple in design, and were incapable of producing distillates of great strength from the wine which invariably was used as the material for distillation. It was indeed found by the early chemists that if the first weak distillate were subjected to a second and third distillation its alcoholic strength could be raised (though at the expense of a material diminution in its volume) to such an extent that it would burn, but the expensiveness of the product thus obtained was too great to allow its use for any industrial purposes.

At present wine and other fermented fruit juices are distilled only for the production of potable spirits; and industrial alcohol is made altogether by the distillation of fermented saccharine solutions which are prepared either directly from raw materials containing sugar, such as molasses, or from starchy materials like potatoes or the cereal grains, after a preliminary treatment which converts their starch into sugar.

THEORY OF ALCOHOLIC FERMENTATION.

The process of alcoholic fermentation is established whenever yeast is allowed to act on sugar solutions of moderate strength at temperatures between 50° and 90° F. Theoretically the process consists of a simple splitting up of sugar into alcohol and carbonic acid gas, any given amount of sugar yielding proportionate and perfectly definite amounts of these two products of its decomposition. This is illustrated in the following example:

The chemical composition of dextrose, which is the form of sugar occurring in most ripe fruits, is represented by the formula $C_6H_{12}O_6$, which signifies that one molecule or unit of the compound substance dextrose is made up of six atoms or units of the element carbon, twelve of the element hydrogen, and six of the element oxygen. When fermentation takes place, the molecule of dextrose breaks up substantially as is indicated by the following equation:

$$C_6H_{12}O_6 = 2\ C_2H_5OH + 2\ CO_2.$$

This signifies that after fermentation is over the dextrose will have disappeared and in its place will be found an amount of alcohol containing all the hydrogen, two-thirds of the carbon, and one-third of the oxygen of the sugar, and an amount of carbon dioxid containing one-third of its carbon and two-thirds of its oxygen. Theoretically the total weights of the alcohol and carbon dioxid which are produced in the fermentation should equal exactly the weight of dextrose which is decomposed, and 100 pounds of the sugar should yield 51.11 pounds of alcohol and 48.89 pounds of carbon dioxid.

In practice, however, the decomposition is never complete, nor is it ever so simple as is indicated by the foregoing equation. Only in carefully conducted laboratory work is it ever possible to ferment any sugar completely; and even then, as a result of life processes of the yeast which are not yet understood by chemists or biologists, small and varying proportions of the sugar escape transformation into alcohol, and are converted instead into other substances. According to the investigations of Pasteur, 100 pounds of dextrose, instead of yielding the theoretical weights of alcohol and carbonic acid indicated by the equation, will produce in laboratory practice the following amounts of fermentation products:

	Pounds.
Alcohol	48.55
Carbon dioxid	46.74
Glycerin	3.23
Organic acids	.62
Miscellaneous	1.23
Total	100.37

The fact that the total weight of the fermentation products exceeds slightly the weight of sugar fermented is explained on the ground that the formation of certain of the by-products is accompanied by the absorption and fixation of slight amounts of water.

In manufacturing work, such completeness of fermentation may be taken as an ideal toward which one is to strive. According to the skill of the distiller, the character of his mechanical equipment, and the quality of his water, yeast, and fermentable materials, his yields of alcohol may approximate those indicated or may, on the other hand, fall far below it.

NATURE OF YEAST.

Yeast, the exciting agent of the alcoholic fermentation, is familiar to the general public chiefly in the form of the small square cakes which are sold at groceries, and to workers in breweries and distilleries as a more or less frothy paste. Whatever its outward form and appearance may be, it always is made up of innumerable microscopic plants which are globular or ovoid in form, approximately 1/4000 inch in diameter, and fairly colorless and transparent as seen under the microscope.

Yeast withstands prolonged exposure to cold without serious injury, but is weakened rapidly when kept at high temperatures, and is killed quickly when heated to about 110° F. It ordinarily reproduces itself by a process of budding, and grows at the expense of various nutrient materials, such as lime, potash, phosphoric acid, and nitrogenous compounds, which it absorbs from the solutions in

which it is placed. The vigor of a fermentation seems to depend largely upon the phenomenon of yeast growth. Good fermentation can not be established without abundant and suitable nutrients for the yeast and its vigorous development.

The selection of a suitable yeast for any purpose and its preparation and maintenance in a pure and vigorous condition are arts which demand thorough training and experience. They can not be learned from books alone and call for no small amount of manipulative skill.

PREPARATION OF SACCHARINE SOLUTIONS FOR FERMENTATION.

Certain saccharine materials, such as the juices of most fruits and of the sugar cane, are in their natural condition so susceptible to fermentation that they can not be preserved unaltered unless they are sterilized in sealed bottles or some antiseptic or preservative material, such as salicylic acid, is added. Other sugar-containing materials, such as molasses, do not ferment readily until they have been subjected to certain preliminary treatments. Thus, both cane-molasses and beet-molasses must be diluted with water before they can be fermented; and since they often are deficient in the nitrogen compounds which are essential to yeast production it sometimes is found necessary to add nitrogen to their solutions in the form of ammonium sulphate or some equivalent material. Furthermore beet-molasses is usually alkaline, and as yeast will not work in alkaline solutions it is necessary to acidify beet-molasses before adding yeast to it. Diluted sulphuric acid is commonly used for this purpose. The amount of water or of chemicals which must be added to a given quantity of molasses to fit it for fermentation will depend upon the composition of the latter. Experience has shown that with ordinary cane-molasses it is desirable to use about six volumes of water for one of molasses. In this way a solution is obtained which contains about 12 per cent of sugar and is capable of producing approximately 6 per cent of alcohol. This proportion of sugar has been found, in general, to give the best results with regard to the rate, completeness, and economy of fermentation.

PREPARATION OF FERMENTABLE SOLUTIONS FROM STARCHY RAW MATERIALS.

While the saccharine raw materials of the fermentation industries can be prepared for use by the relatively simple processes of solution or juice expression, such materials as potatoes and grain, which contain little sugar and much starch, must be subjected to special treatment in order to convert the insoluble and unfermentable starch into sugar. The series of operations by which this starch conversion is accomplished is called "mashing," and consists of a preliminary

scalding or cooking process, the purpose of which is to liquefy the starch, and of the saccharification proper, in which the soluble starch is converted into dextrin and sugar. The agency by which the latter conversion is accomplished is the specific action (in the presence of moisture, and at a suitable temperature) of certain substances called enzyms, which usually are developed for this particular purpose in a portion of the grain used for mashing, by a process called malting.

Malting.—When the seeds of any cereal are moistened and allowed to sprout, changes in their chemical composition take place which are fully as striking as the accompanying changes in the appearance of the grains. Most important of these is the formation of bodies which have the power, when dissolved in water and allowed to act at a suitable degree of warmth, of corroding the insoluble starch granules of the grain, of rendering them soluble, and of converting the starch ultimately into a fermentable sugar called maltose. Grain which has been treated so as to develop these bodies is called malt.

These enzyms, or active bodies of the malt, are usually grouped under the name diastase, and they appear during the sprouting of all starchy seeds. Their formation has been utilized technically in the case of several of the cereals, such as wheat, rye, oats, maize, and barley. Rye and barley produce diastase more abundantly than the other grains, and are employed in large quantities in the malting industry. Of the two, barley is most used on account of the protection which is afforded by its husk to the tender kernel of the grain during the rough handling incidental to the malting process.

In making malt the barley is cleaned thoroughly by screening and washing, and is then steeped in water until the grains have absorbed enough water to soften them thoroughly and prepare them for germination. The excess of water is then drained off, and the wet grain is spread evenly on a smooth and scrupulously clean floor in a well-ventilated room which can be kept at a temperature of about 55° to 60° F. The grain is turned frequently, with wooden shovels, to keep it uniformly moist and to prevent its overheating, and as sprouting progresses it is gradually spread over a greater floor area so that a pile which originally was from 12 to 18 inches deep may finally have a depth of only 3 or 4 inches.

Malt which is intended for shipment is usually grown for about a week at a temperature not exceeding 68° F., after which it is dried slowly in kilns that are gradually raised from 95° to 125°, until only 2 or 3 per cent of moisture remains. Malt which is made in the distillery where it is to be used may be grown at about 55° for three or four weeks, and should then be used without having been dried. Green malt, thus prepared, has a much higher diastatic power[1] than the dried malt of commerce.

[1] The power of converting starch into sugar.

One hundred pounds of good barley will make about 75 pounds of kiln-dried distiller's malt, which will be strong enough to saccharify about 1,000 pounds of raw grain (maize). The same barley, grown longer and used as green malt, can be made to saccharify nearly twice as much raw grain.

In converting starch into sugar, malt diastase exerts two distinct forms of chemical activity—liquefaction, and saccharification. The intensities of these activities depend largely upon the temperature at which the diastase is made to act upon the starch, and the two forms of activity are differently affected by alterations in this temperature. The liquefying power is exerted most strongly at about 158° F., is weakened at approximately 175°, and is destroyed at about 200°. The saccharifying power is strongest between 120° and 130° F., is weakened seriously at 145°, and is destroyed completely at 175°. These facts show the need of drying distiller's malt at a relatively low temperature, and indicate the temperature limit below which saccharification must be conducted.

Mashing.—The first stage of every mashing is a scalding, which gelatinizes and partially liquefies the starch of the raw materials. When this preliminary cooking has gone far enough, the mash is cooled somewhat and malt is added, whereupon the liquefaction is completed and the soluble starch is more or less completely converted into maltose. The form of the mashing apparatus and the temperatures at which the several operations are conducted are modified as may be necessary to fit the peculiarities of the raw materials.

In this country maize is the chief starchy material used in the manufacture of alcohol. It is mashed in a sort of kettle known as a vacuum cooker, which is illustrated in figure 1.

The vacuum cooker is a horizontally placed cylindrical vessel made of steel boiler plate, and has a capacity of about 40 gallons for every bushel of grain to be mashed in one charge. Just below the center of each end it is provided with stuffing boxes, through which a shaft passes. The latter carries several rakes or stirring arms inside the shell; outside it is provided with a strong toothed wheel, arranged for chain drive. Thermometers and try cocks are mounted in each end of the shell, and if the cooker is large a third thermometer is set in the middle of the side. In a row along the bottom are several small steam-inlet valves so constructed that while steam can pass freely into the cooker the contents of the latter can not run back into the steam pipe when pressure is removed outside. At the middle of the top of the cooker is a dome fitted with a pipe connection which leads to a "cross." From one side of the latter connection is made to the steam supply, which must be carried at about 50 pounds pressure; from the other side connection is made with the vacuum pump, and from the top a pipe leads to a blow-off valve. On top of the

cooker, at one end, there is a manhole through which water and meal may be introduced, and in the bottom, at one end, there is a discharge valve which opens into a pipe leading to the drop tub. The operation of this cooker is as follows:

Water in the proportion of 20 to 25 gallons for every bushel of corn is first run in and is warmed up to about 120° F. The rakes are then started and the grain, which should be ground to a coarse meal, is added slowly enough to keep it from forming lumps. When the meal is all in, the manhole is closed and steam is turned on through the small valves in the bottom, the blow-off valve being left open.

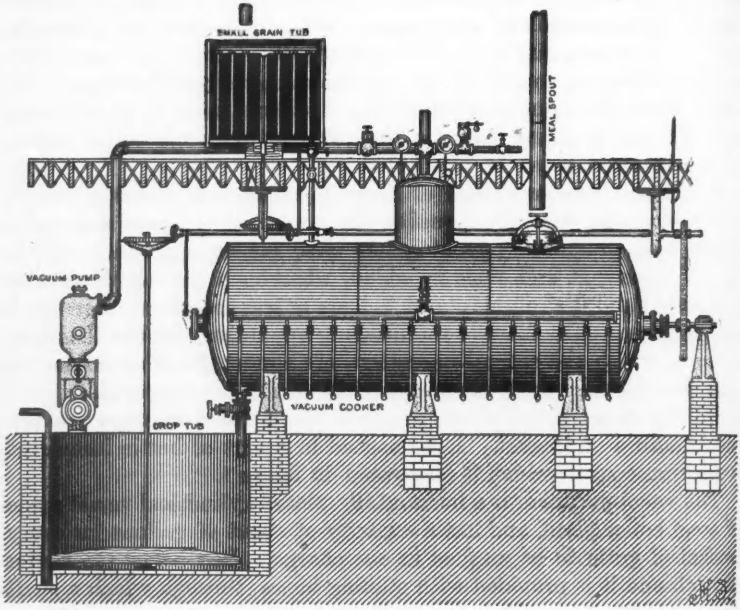

FIG. 1.—American vacuum cooker.

When the temperature of the mash has risen to 212° the blow-off valve is closed and pressure is allowed to rise within the cooker at such a rate that the thermometers and a pressure gauge in the dome indicate a fairly constant equalization of temperature in the contents. The pressure is allowed to rise to about 50 to 55 pounds, corresponding to a temperature of about 300° F., but is maintained at this point for a few minutes only, after which the steam is shut off and the blow-off valve is opened until the pressure is completely relieved. The blow-off valve is then closed again, and the valve between the cooker and vacuum pump is opened. Application of the vacuum causes renewed boiling and a rapid fall of temperature in the contents

of the cooker, and when the thermometers read from 140° to 145° F. the vacuum is released and the malt is added.

The amount of malt employed is usually about one-tenth of the weight of corn in the mash. It is ground quite fine and is mixed in the small grain tub with enough lukewarm water to make it flow freely through the pipe which leads to the cooker. The length of time allowed for saccharification in the cooker will vary from fifteen minutes to an hour, according to the temperature—which should be held between 140° and 145° F.—and the amount and diastatic strength of the malt. It is advisable not to hasten this part of the mashing process unduly, and the completeness of the starch conversion should always be proved before pumping the mash through the coolers into the fermenting cisterns.

The apparatus and mashing process described are designed primarily for use in corn distilleries, but they may be adapted with but little change to use with potatoes as a raw material.[1]

FERMENTATION.

In order to minimize the chances for souring and spoiling, the saccharine solution intended for fermentation is pumped to the fermenting cisterns as soon as possible after its preparation. Yeast, which in the meantime has been prepared [2] separately in a small tub from a mash containing malt and either rye or potatoes, is added to it at once in a proportion varying between 5 and 10 per cent. If necessary, water is added to fill the cisterns to within a few inches of the top, and the whole volume of liquid is thoroughly plunged or mixed. At this time the solution should contain between 17 and 22 per cent of solids, as shown by a reading of 17° to 22° on the Balling saccharometer, and its temperature should be between 60° and 65° F.

Within a few hours gas bubbles will begin to break the surface of the fermenting liquid, forming a constantly thickening cap of foam, and the whole mass of beer will rapidly come into vigorous motion. At the same time its temperature will begin to rise, and its specific gravity, as indicated by the saccharometer, will fall. According to the temperature, the kind of material fermented, and the strength of the yeast, fermentation will be complete within from 48 to 96 hours, as will be shown by the gravity and temperature ceasing, respectively, to fall and to rise, by the solution coming to rest and losing its foamy cap, and by cessation of the escape of gas bubbles. The fermented liquor, or distiller's beer, is now said to be "dead" or "ripe," and is ready for distillation.

[1] See Farmers' Bulletin 410, p. 11.
[2] Detailed directions for making yeast are given on p. 25 of Farmers' Bulletin 410.

If the composition of the mash and the degree of fermentation are satisfactory, the beer should increase about 30° F. in temperature above the point at which it was set, its gravity should fall almost to 0° Balling, and it should contain between 6 and 10 per cent of alcohol.

DISTILLATION.

The separation of alcohol from the fermented liquors in which it is formed is made possible by the fact that its boiling point, 173° F., is lower than that of water by nearly 40° F. On this account a mixture of alcohol and water boils at a lower temperature than water alone, and the vapors which first arise from such a boiling mixture are richer in alcohol than the liquid itself. Thus, a mixture of alcohol and water which contains 8 per cent by weight of alcohol, will boil at

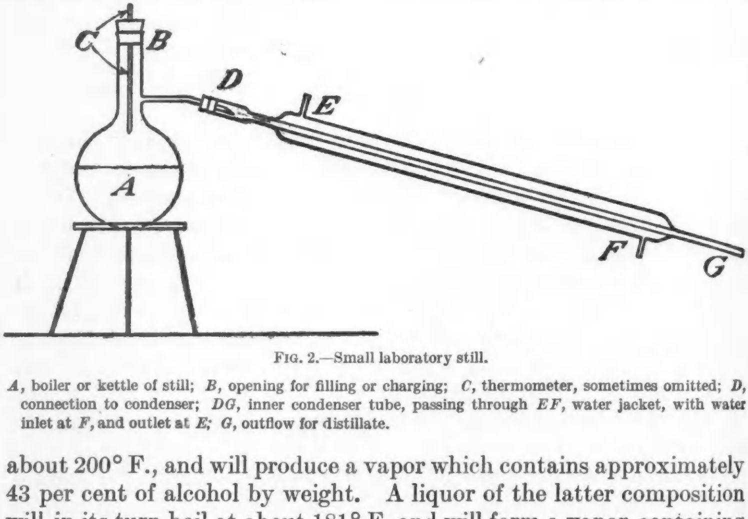

FIG. 2.—Small laboratory still.

A, boiler or kettle of still; *B*, opening for filling or charging; *C*, thermometer, sometimes omitted; *D*, connection to condenser; *DG*, inner condenser tube, passing through *EF*, water jacket, with water inlet at *F*, and outlet at *E*; *G*, outflow for distillate.

about 200° F., and will produce a vapor which contains approximately 43 per cent of alcohol by weight. A liquor of the latter composition will in its turn boil at about 181° F. and will form a vapor containing about 68 per cent of alcohol. When such mixtures are distilled all of their alcohol, mingled with more or less water, will pass over into the distillate, while a considerable proportion of the water still remains in the kettle of the still. It is possible, therefore, even with stills of such simple type as are outlined in figures 2 and 3, to obtain ultimately a fairly strong alcohol by repeated distillation of the successive distillates.

Such a still as is shown in figure 3 will produce in two successive distillations (singling and doubling) from 100 volumes of a beer containing approximately 10 per cent of alcohol about 37 volumes of a distillate of 67 per cent strength together with about 23 volumes of weak distillates which can be saved for subsequent redistillation. It

would be impossible, however, to make any quantity of a 90 per cent distillate with such an apparatus except by incurring an expense for fuel and labor which would far exceed the highest possible industrial value of the product.

Fortunately it is possible so to construct a still that the requisite number of redistillations take place simultaneously in a single apparatus with little more outlay for fuel and labor than would be required to subject the same volume of beer to a single distillation in the pot still shown in figure 3. Such a complex apparatus, known as a column still, costs much more to build than does a simple still of the same beer capacity, but its almost automatic action and the saving which

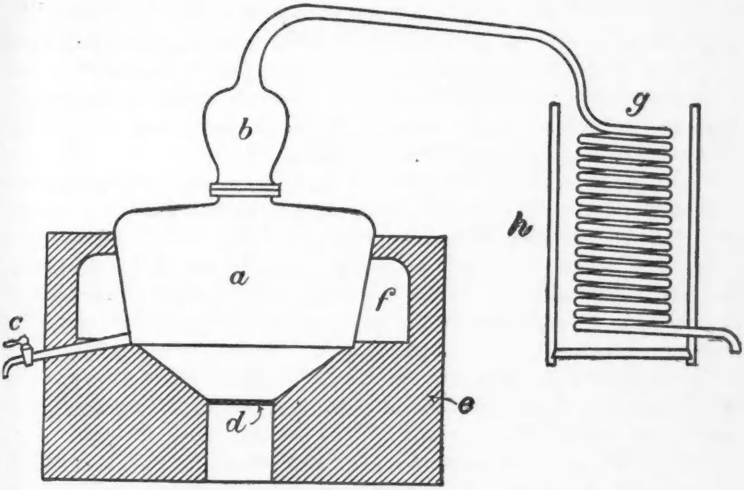

FIG. 3.—Fire-pot still.

a, Kettle of still; b, head of still; c, draw-off cock; d, grate; e, masonry support; f, flue; g, condensing worm; h, worm tub.

it affords with regard to labor, fuel, and water make it a necessary investment for any distillery which is designed to produce industrial alcohol.

Detailed instructions for the operation of a column still and an illustration showing its various parts are given in Farmers' Bulletin 410, page 17, and will not be here repeated. Although the details may seem somewhat complicated, the actual management of a continuous still is in fact quite simple. When its operation is once well under way a condition of equilibrium is established in the working of its various parts, and as long as the supplies of water, steam, and beer are kept uniform it is possible to maintain a steady flow of distillate of practically constant proof for hours at a time, with comparatively little attention from the distiller.

GOVERNMENTAL CONTROL OF A SMALL DENATURED-ALCOHOL DISTILLERY.

Certain important features of the regulations of the Bureau of Internal Revenue are of special interest to those to whom the subject is new.

First of all, the mere possession of any still or distilling apparatus set up, even though the same is not employed in distilling alcohol, subjects its possessor or custodian to heavy penalties unless he has registered it in writing with the collector of internal revenue for the district in which it is located. The distillation of alcohol is forbidden by law, except when conducted in accordance with the regulations issued by the Bureau of Internal Revenue and under the supervision of a designated officer, no matter how much the alcohol may be mixed or diluted with other substances. These facts are emphasized because they directly contradict the statements sometimes made that apparatus and processes can be furnished by which denatured alcohol can be made without Government supervision.

Other points worthy of mention in this connection are as follows:

Distilleries are to be constructed and their machinery is to be arranged in compliance with the regulations. (Secs. 14–24, pp. 45–50.[1])

The distiller must own or control the land on which the distillery is erected. In case that he does not own it or that it is mortgaged he must file the written consent of the owner or mortgagor to its use for distillery purposes. (Sec. 4, p. 41.)

The distiller must give written notice of his intention to engage or continue in the distilling business, stating what kinds of material he intends to use. (Secs. 5 and 13, pp. 41–42 and 45.)

The distillery, when ready for operation, must be "surveyed" by a designated Government official. (Secs. 25 and 6–12, pp. 50 and 42–45.)

Before beginning operations, the distiller must file a bond, signed by himself and two sufficient sureties, for an amount not less than the tax on all the spirit that the distillery could produce in a month. (Secs. 26–27, pp. 50–52.)

The survey having been made and the bond filed, the distiller must give notice of the day on which he will begin operations. (Sec. 29, p. 52.)

Records must be kept by the distiller, for inspection by the revenue officers, of the amounts and kinds of material received and used and of the amount of alcohol produced. (Secs. 34–37, pp. 54–57.)

No kind of spirit save alcohol for denaturing purposes can be produced at an industrial distillery. (Sec. 38, p. 57.)

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[1] U. S. Internal Revenue Reg. No. 30, rev.

When a revenue officer is assigned to a distillery, it must be operated regularly on every day except Sundays. (Sec. 39, p. 57).

Methods are prescribed by which denaturants may be obtained and used. (Secs. 41–44 and 49, pp. 58, 59, and 61.)

FACTORS INFLUENCING THE COST OF MANUFACTURING ALCOHOL.

While cheap and abundant raw material is indeed essential to the profitable production of denatured alcohol, there are other factors, no less important, which enter into the cost of manufacture. Some of these are as follows:

Interest and depreciation.—A small distillery can hardly be built and equipped for less than $12,000. Interest on the investment may therefore be set at about $700 a year; and a like amount ought to be allowed for keeping the plant in good working order. The capacity of such a plant can be doubled without any very great increase in cost; and if the capacity be halved, the reduction in cost will be relatively small.

Labor.—At least three and probably four men will be needed to run any distillery, however limited its capacity. Increase of the production up to 400 or 500 proof gallons daily would probably not call for additional labor. Five men undoubtedly could handle a plant producing 1,000 gallons daily.

Water.—A large amount of pure cold water is needed for the operation of a distillery. This fact is generally unknown, save to those who are engaged in the distilling business. A plant capable of producing 100 proof gallons, or 55 gallons of 180° alcohol, in a working day of ten hours, will need a supply of water amounting to not less than 3,000 gallons in that length of time, or five gallons per minute, and may demand considerably more.

Fuel.—Little definite information is available regarding the amount of fuel necessary for the operation of a small alcohol distillery. This dearth of accurate knowledge is regrettable, for the coal bill is a prominent item in the distillery's expense account. Such data as are at hand indicate that the coal consumption—per gallon of 180° alcohol produced—may vary from 11 pounds under the most favorable conditions to 38 pounds in a poorly equipped and poorly managed plant. As 11 pounds of coal as a distillery fuel yield almost 159,000 heat units and a gallon of alcohol gives about 75,000, it is apparent that the use of alcohol so produced for heating would involve a great waste and be altogether unprofitable. Furthermore, the coal consumption of a small distillery will be proportionally greater than that of a large one, since many economies which are possible in a large plant are quite impracticable in a small one.

CONCLUSIONS.

It is apparent that the business of distilling alcohol is one which calls for a considerable investment and no small degree of technical skill. It can not be conducted advantageously, from a commercial point of view, in very small plants on account of the proportionately high cost of the plant and of labor; and many of the so-called "wastes" which have been suggested as fermentable raw materials are so poor in fermentable substance or so expensive to handle that their availability is thereby impaired. It seems that the business, to be productive of satisfactory returns, must be conducted on a fairly large scale, and that the best success is likely to be attained with raw materials of the general types already in use, namely, maize, potatoes, and molasses. The industry is not suited to every locality, and it is most likely to be successful if carried on systematically on a very large farm, or if supported by the joint interests of a fairly large community. The alluring statements sometimes made regarding large financial returns to be obtained by making industrial alcohol with waste raw material, unskilled labor, and a "cheap" distilling outfit are misleading and can only result in loss if followed.

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